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SOME EFFECTS UPON THE LEG OF PRONATION OF THE FOOT.

BY

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During the past few years a large amount of attention has been given to the study of the foot. Its anatomy has been most accurately described in every detail; and the changes in form which it undergoes when subjected to weight have been the subject of almost endless experiment and examination. It is not the purpose of the present paper to discuss points that have been so amply gone over before, but rather to call to your attention some few facts concerning the behavior of the leg which are induced by that series of changes in the shape and position of the foot which have of late been referred to as "excessive pronation."[1] So intently has the attention been fixed in this study upon the behavior of the foot itself that very little has been said or thought about its relations to the leg other than that of the point of projection of the centre of weight-bearing as it is seen to move inward with increasing eversion of the sole. In fact, it is the all but universal custom in our descriptions to regard the leg as the fixed point and to speak of the various movements of the foot in their relation to that. However true this may be of the foot when hanging freely in the air, it certainly ceases to be so as soon as the foot is placed upon the ground. From the moment that the weight of the body is thrown upon a foot, the sole of which is resting upon a relatively even surface, the greater part of that foot is thereby anchored and becomes the fixed point. The change in relative positions which we commonly refer to as "abduction of the foot," is, as far as motion is concerned, really "adduction of the leg," and so on throughout the list.

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[1] "The Affections of the Arch of the Foot, commonly Classified as Flat-foot." Lovett and Dane: New York Medical Journal, March 7, 1896.

That the foot was really the fixed point was first brought forcibly to the attention of the writer by a study of some photographs, taken with double exposures upon the same plate, made when preparing a joint paper with Dr. Lovett, which was read before this Association two years ago.[1] In such pictures it can be seen at a glance that while the double outline from the malleoli upward shows a change of position of the leg, the toes and the greater part of the foot must have remained absolutely stationary. In a later paper[2] Dr. Lovett emphasizes this fact when he says: "The toes remain practically stationary, while the whole leg rotates inward at the hip," and he has made excellent use of this fact in his construction of a triangle for measuring the amount of "rotation" the angles of which are respectively the external malleolus, the cleft between the third and fourth toes, and the internal malleolus. Still later Dr. James S. Stone, in his paper read at the annual meeting of the Massachusetts Medical Society, June, 1896,[3] has carried the idea further than anyone else when he says: "Pains in the calf are usually due to muscular strain, while those in the knee or hip may be explained by the rotation of the whole limb, due to the impossibility of any rotation of the astragalus between the two malleoli."

In speaking of the changes brought about in the relations of the ankle-joint by pronation of the foot, all discussion as to the exact seat of pronation is, for the sake of simplicity, purposely avoided. The changes in position of the malleoli are regarded simply as the result of series of changes taking place between them and the astragalus, between the astragalus and the os calcis, and along the line of the middorsal joint of the foot. The ankle-joint proper, formed by the gripping of the articular surfaces of the astragalus between the malleolar extensions of the tibia and the fibula, one on either side, is so constructed that it allows of flexion and extension, and practically nothing else. This purely hinge-motion takes place about a line drawn between the central points of the two malleoli or very near to it. But as the central point of the external malleolus is situated not only in a lower horizontal plane than the corresponding point of the internal malleolus, but also lies more posteriorly, it follows that the plane of the hinge of the joint varies from that of a right angle to the long axis of the leg in two ways. Just what this variation is has not been very accurately stated, either in the text-books or special monographs. Walshan and Hughes[1] refer to it thus: "When standing with the foot at a right angle to the leg the straight line joining the centre of the two malleoli lies in a plane directed forward and outward." Quain[2] speaks of it as the "obliquity of the ankle-joint, which forms with its fellow, owing to the outward direction of the foot, an angle, open backward of about 130 degrees."

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[1] "The Affections of the Arch of the Foot," etc. TRANSACTIONS OF THE AMERICAN ORTHOPEDIC ASSOCIATION, vol. viii., p. 78.

[2] "The Mechanics and Treatment of the Broken-down Foot." New York Medical Journal, June 20, 1896.

[3] "The Treatment of Flat-foot." Boston Medical and Surgical Journal, June 14, 1897.

With the view of determining this with a little more exactness, a set of measures was made upon the feet of adults and older children; the best feet obtainable being used. With the subject in the standing posture, the bare foot was placed upon a piece of cardboard and just enough weight thrown upon it to keep it steady. Its outline was then traced with a pencil, held by means of a special apparatus, at a right angle to the floor. Upon this outline the vertical projection of the central point of each malleolus was marked. Lastly, these marked points were connected upon the cardboard by a straight line. The angle of divergence of this line to another drawn parallel to the long axis of the os calcis was then measured. This it was assumed gave the obliquity of the hinge of the ankle-joint in a horizontal plane. This was found to average between 84° and 85°; or taking the two feet together, an angle open backward of 169°. (See Fig. 1.)

The angle of obliquity in a vertical plane was found by measuring the height from the floor to the central point of each malleolus; also the distance from centre to centre as measured by compasses. These points having been plotted upon paper and connected with a straight line, the angle of divergence of this line from the perpendicular was easily measured. This was found to average about 77°; or, taking the two joints together, an angle open downward of 154°. (See Fig. 2.)

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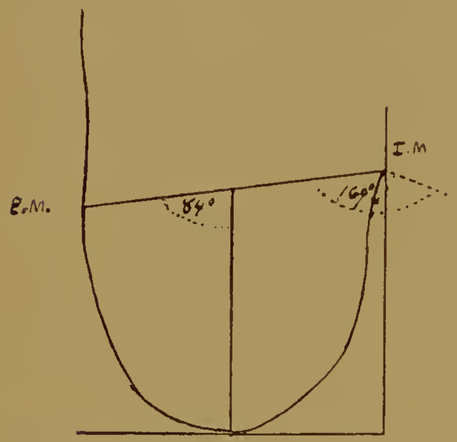
[1] "Deformities of the Human Foot," p. 24.
[2] "Quain's Anatomy," tenth edition, vol. ii., p. 192.

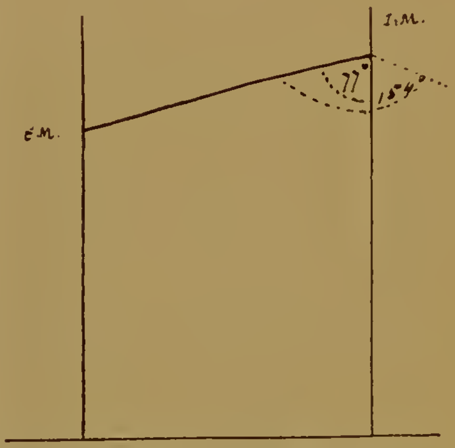
The next question is: What is the behavior of the malleoli, comprehending as they do between them the plane of the ankle-joint, when weight is thrown upon the normal foot? Fortunately this question has been investigated in the most careful manner by Golebiewski.[1] His method was to take a series of accurate plaster casts of the feet in various positions and under varying amounts of weight, and on these casts to make careful measurements of the relations of selected and marked points. His conclusion is[2] that "When one so holds himself as to stand upright and the foot makes a right angle with the lower leg, then the tibia again makes a small outward rotation, whereby the internal malleolus must again move forward and the external backward." His actual figures as far as the present inquiry is concerned may be abbreviated and put in tabular form thus. They are somewhat confusing, however, from the difference in the two feet, that for the left being used here as that is apparently the one from which he draws his conclusions:

FIG. 1.



Showing obliquity of the normal ankle-joint in the horizontal plane.

FIG. 2.



Showing obliquity of the normal ankle-joint in the vertical plane.

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[1] Golebiewski: Zeitschr. fur Orthopadische Chirurgie, B. iii., s. 243.

[2] Op. cit., s. 246.

Measurements in millimetres.		Downward.	Forward.	Backward.
Internal malleolus	with body weight	4	3.5	
	" " " + 50 kg.	6	4.5	
External malleolus	with body weight	7	......	1
	" " " + 50 kg.	11	......	4
Tuberosity of scaphoid	with body weight	5		
	" " " + 50 kg.	6.5		
Tuberosity of 5th metatarsal	with body weight	17		
	" " " + 50 kg.	20		

These figures show that when the foot is subjected to weight the external foot-arch descends much more than does the internal; and the external malleolus drops downward farther than does the internal malleolus. The result of this relatively greater descent of the outer end of the hinge of motion of the ankle-joint is an increase in its obliquity as regards the perpendicular. But what is of even more importance for our present inquiry is the backward rotation of the external malleolus and the forward rotation of the internal. This alters in a second way the line of flexion of the joint and increases its outward obliquity in a horizontal plane.

To understand the significance of these changes as well as those that take place in the pronated foot, it is necessary to consider the mechanism by which the weight of the body is made to assist so greatly in maintaining the erect attitude, that practically we are enabled to stand without much muscular exertion. These theories were first brought forward by Prof. Meyer, of Zurich, and have since been elaborated in his many publications.[1] He has shown that when standing in the erect position the weight of the trunk and upper extremities is transmitted downward in a line that falls behind the centre of motion of the hip-joints. The tendency, therefore, is for the pelvis to "fall backward by over-extension of the hips;" but this tendency is met after a slight amount of motion, by tension on the extremely resistant anterior portion of the joint-capsule known as the ilio-femoral ligament. The strength of this ligament is more than sufficient to hold the joint locked. This mechanism enables the thigh bones to support the weight of the trunk when in this position, in great measure without muscular exertion and its consequent fatigue. All other positions, necessitating, as they must, a much greater muscular effort to maintain them, very soon become tiresome. In this connection it is important to note that, owing to the partially oblique course of the ilio-femoral ligament, tension upon it will result in a slight inward rotation of the thigh, the significance of which will be considered later.

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[1] H. von Meyer, Muller's Archiv., 1853, s. 32, u. s. 500. His und Braune's Archiv., 1880, s. 289 ff. Statik und Mechanic des Menschlichen Fusses, June, 1886.

The tilting backward of the pelvis, with its consequent raising of the anterior-superior spines and adjacent parts of the iliac crests, not only serves in the way just pointed out to lock the hip-joints, but it plays a most important part in preventing flexion of knees as well. The line of weight is transmitted downward by the thighs, behind the axis of motion of the knee-joints, which must for security in standing be locked in extreme extension. As described by Quain,[1] the knee "is not exactly a hinge-joint, and extension and flexion . . . are produced by a combination of gliding, rolling, and rotation . . . In the movement of extension the condyles move parallel to one another, both gliding and rolling until extension is nearly completed, and then, the anterior part of the rolling surface of the external condyle having already come into full contact with the tibia, the inner condyle continues to glide backward, bringing its oblique anterior part into contact with the tibia, so that the femur is rotated inward on the tibia. Similarly, the beginning of flexion is accompanied by a rotation outward of the femur or inward of the tibia." That is to say, the knee-joint is finally, as it were, locked in complete extension by a rotatory twist, which must be overcome before flexion is possible. The anatomical construction of the joint itself causes this twist as it approaches complete extension, but the structures on the outer side of the leg are of great assistance in maintaining it. Connecting the outer tuberosity of the tibia and the anterior part of the iliac crest is that dense thickening of the fascia lata, known as the ilia-tibial band, reinforced by the tensor vaginæ femoris and biceps muscles. When, as already described, the anterior part of the iliac crest is raised by a tilting backward of the pelvis, these structures are put upon the stretch. The result is not only a still firmer pressing together of the joint-surfaces at the knee, but a powerful check to any inward rotation of the tibia—a check so effective that it must be overcome by tilting the pelvis forward or flexing the hip-joints before the knee-joint can be unlocked enough to allow flexion there.

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[1] "Quain's Anatomy," tenth edition, vol. ii., p. 188.

In the ankle-joint the problem of supporting the body-weight with a minimum of muscular exertion differs in many ways from that in the hip and knee. Here the position to be maintained is one midway between flexion and extension, therefore a locking of the joint at one limit of its arc of motion is out of the question. As we stand in the upright position the line of weight falls in front of the axis of motion of the ankle-joint. The constant tendency is, therefore, for the tibia and fibula to fall forward; the resulting motion being generally referred to as "dorsal flexion of the foot." The mechanism which prevents this flexion is in large measure dependent upon the obliquity of the line of motion of the ankle-joints. This obliquity, which we turned aside to consider in the early part of this paper, amounted to an angle open backward of 169°, and downward of 154°, when the two joints are considered together. Were the axes of motion of the ankle-joints set at a right angle to the long axis of the legs, it is easy to see that there would be no impediment to the two legs falling forward parallel to each other, even with the knees fully extended. Not so in the case of the normal foot; for, owing to the marked obliquity of its axis of motion, a new factor is at once added. In order to flex two such joints simultaneously, it would be necessary either to carry the heads of the femora in opposite directions, which is a manifest impossibility, or to flex the knees, which is precluded by the mechanism that we have just been considering. The result is, therefore, a comparatively stable ankle-joint even in a midway position of its arc of motion. It remains, in passing, but to add that the outward rotation of the tibia and fibula, that we saw was an accompaniment of the final act of extending the knee, is such as to make the ankle-joint still more oblique, and consequently still more stable when called upon to support the body-weight.

Turning now from the normal to the pronated foot we shall find that the conditions are altered in just such a way as to hamper, if not to render impossible, the working of the entire mechanism that we have just been considering. To study the behavior of the lower

Fig. 3.

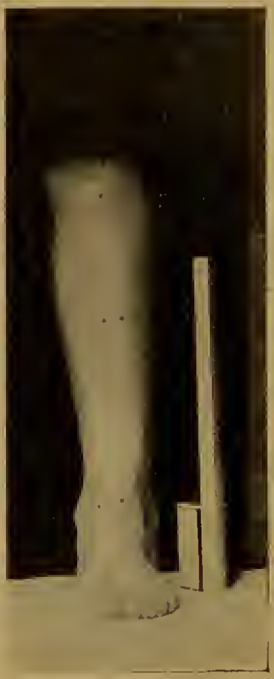


Fig. 4.

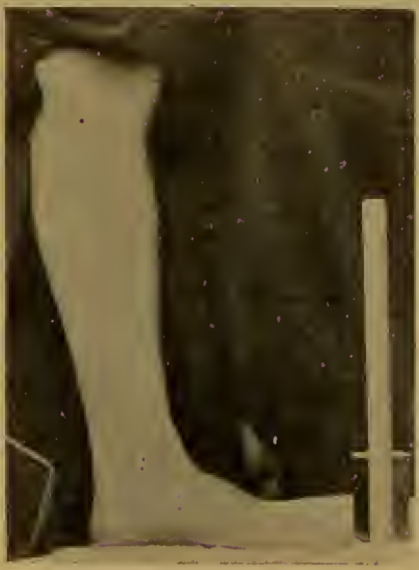
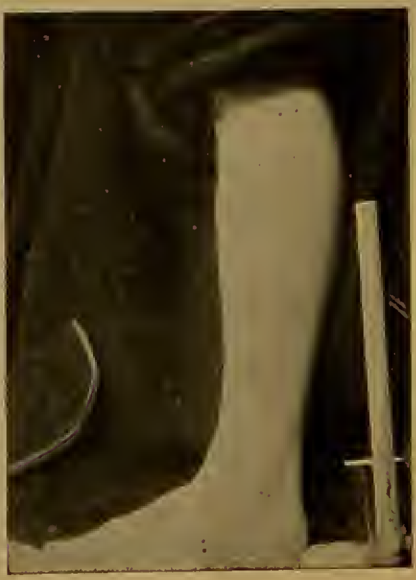


Fig. 5.



extremity as altered by pronation of the foot, the method of double exposures upon a photographic plate was used in the manner already described, but further modified by reducing the markings upon the skin to a set of fine dots, and placing a measure in the same antero-posterior plane as the marked points. With the aid of a pair of callipers it was easy upon such a plate to measure the actual distances moved by any one of the marked points, and then to translate it into terms of millimetres. The results are given for the feet shown in Figs. 3, 4, 5, 6, and 7, in the following table. The alteration in the obliquity of the hinge of the joint when supporting the body-weight is shown by the dotted lines in Fig. 8 for the horizontal alterations, and Fig. 9 for the vertical :

FIG. 6.

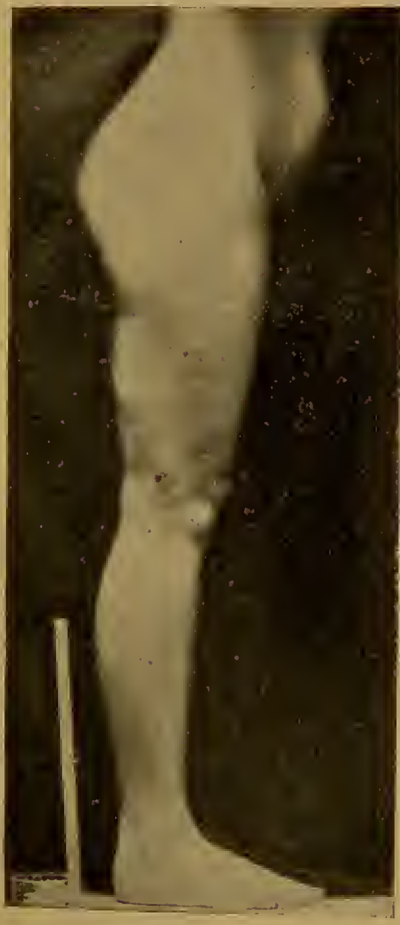


FIG. 7.

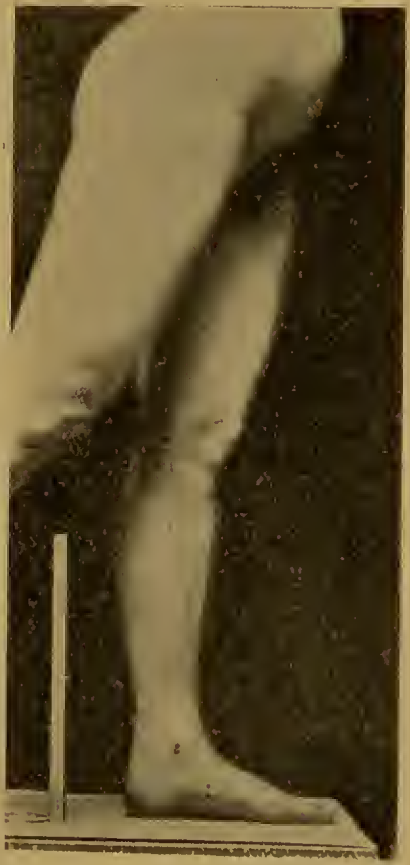
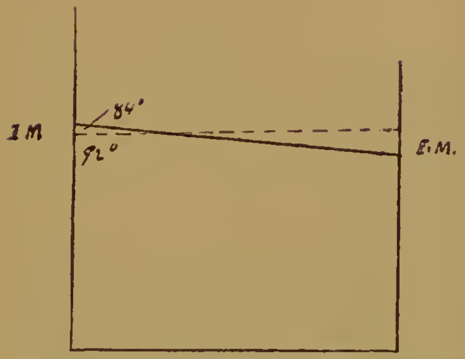
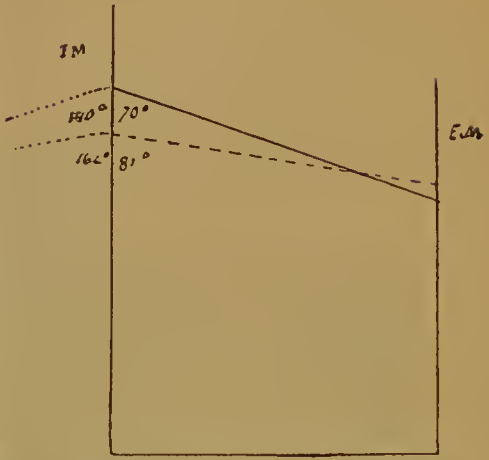


FIG. 8.



Showing alteration in hinge of ankle-joint under weight in horizontal plane. (The upper angle here should read 82° not 84°.)

FIG. 9.



Showing alteration of hinge of ankle-joint under weight in vertical plane.

Measurements in millimetres.	Model.	Upward.	Downward.	Inward.	Backward.	Forward.
Tuberosity of tibia	1 2	... ...	2 3	13 18		
Middle of shaft of tibia	1 2	... ...	3 3	17 16		
Lower edge of tibia	1 2	... ...	5 3	23 15		
Internal malleolus	1 2	... ...	9 5	20 11	2 2	
External malleolus	1 2	4 ...	... . .	16 9	... ...	9 7
Head of fibula	1 2	... ...	... 4	... ...	... ...	15 15
Internal condyle tibia	1 2	... ...	3 2	... ...	3 2	
Tuberosity of scaphoid	1 2	... ...	11 11	... ...		
Tuberosity of the 5th metatarsal	1 2	7 5	... ...	... ...		
Middle of shaft of femur	2	...	2	20		
Great trochanter of femur	2	...	4	...	...	20
Inside of upper thigh	2	...	2	...	1	

Angle of plane of joint to perpendicular without weight	. . . .	70°
" " " " with "	. . . .	81
" " " long axis foot without "	. . . .	82
" " " " " " with "	. . . .	92
Alteration in plane of joint under weight vertically	. . . .	11
" " " " " horizontally	. . . .	10

Figures 3, 4, and 5 are model No. 1. Figures 6 and 7 are model No. 2.

From these figures we see that the behavior of the pronated foot differs sharply from that of the normal foot under like circumstances. Owing to a transference of the centre of weight-bearing inward, it is the internal arch of the foot that descends the more; indeed, the external arch actually rises. This causes a vertical lowering of the internal malleolus and a rising of the external malleolus; whereas in the normal foot the external malleolus should show the greater fall. The effect of this movement upon the ankle-joint is easy to appreciate; it changes the normal outward obliquity of the axis of motion to a direction much more nearly horizontal. Such a joint offers distinctly less obstacle to a falling forward of the tibia and fibula under the pressure of the body-weight.

Added to this there is a rotatory twist of both bones of the lower leg in what may be called the wrong direction. Instead of remaining stationary or rotating very slightly outward so as, by complementing the inward rotation of the femur, to make the locking of the knee-joint still more secure, we see here a slight backward movement of the internal malleolus and a much more marked forward movement of the external malleolus. Meanwhile the head of the tibia is seen to have moved very little, but the head of the fibula has made a large excursion forward. Taken as a whole, this shows a complicated inward rotation of both bones of the lower leg about an oblique axis which passes through the inner border of the internal condyle of the tibia and just to the median side of the internal malleolus.

The results of these movements are many: First, the horizontal plane of the ankle-joint no longer looks outward, as it should, but looks slightly inward, thus still further doing away with the mechanism which renders the joint stable under weight, and throwing still more work upon the muscles. Next, by the forward and inward movement of the external malleolus the action of the peroneus longus muscle is much interfered with, and its origin and insertion are brought nearer together. As a consequence, it is contracted, and, owing to repeated strain due to its shortening, we find markedly sensitive points at its origin and the place where its tendon winds over the outer edge of the cuboid. As regards the knee, this inward, or reversed, rotation of the tibia and fibula tends to destroy the whole so-called "final rotation mechanism" by which the joint should be locked when brought to complete extension. From their efforts to prevent as much as possible this inversed rotation of the lower part of the leg, we find the tensor vaginæ femoris and biceps muscles to have been much overtaxed. Together with the ilio-tibial band, which has suffered in the same way, they are generally swollen and tender upon pressure or exercise. In the thigh, as shown by the movement of the marked points on the skin, the normal inward rotation of the femur has been increased, in order, it would seem, to try and counterbalance the inversed rotation of the lower segment. The consequence of this is an undue strain upon all the external rotators of the hip and an irritation of the sacral nerves, thus explaining the state of tenderness and the tonic contraction so frequently found in the gluteal group of muscles, without any reference to so-called "reflex spasm" coming directly from the foot.

SUMMARY. 1. In "pronation of the foot" the greater part of the foot remains stationary and the leg rotates upon it.

2. In addition to the generally recognized motion of the malleoli inward and slightly downward, the normal outward rotation of the tibia and fibula is replaced by an exaggerated rotation inward, which takes place about a nearly vertical axis located near the inner border of the tibia.

3. These changes acting together produce an alteration in the obliquity of the axis of flexion of the ankle-joints sufficient to destroy the mechanism by which the normal joints are enabled to support the body-weight with a minimum of muscular exertion. As a consequence, flexion must be prevented and equilibrium maintained wholly by muscular force, which soon leads to irritation and fatigue of all the muscles of the lower leg, and especially the peroneus longus.

4. This inversed rotation of the tibia interferes to a great extent with the operation of the mechanism by which complete extension of the knee should lock the joint and render it proof against the constant tendency of the body-weight to flex it. The knee must, therefore, in subjects with pronated feet, be kept in extension by a constant exercise of muscular force which results in the fatigue and tendency to tonic spasm of the muscles of the thigh. This is shown also by the extreme tenderness often found over the point of

insertion of the internal hamstring muscles on the inner tuberosity of the tibia.

5. Owing to the constant attempt of the muscles on the outer side of the thigh to prevent the internal rotation of the lower part of the leg they are commonly found to be tense and sensitive to pressure.

6. To try and compensate for this inversed rotation of the tibia and fibula there is an exaggerated inward rotation of the femur. This in its turn overstretches the external rotators of the hip, as shown by sensitiveness to pressure and tonic spasm of the glutei, and tenderness over the points of exit of the sacral nerves.

7. Lastly, this explanation is wholly in accord with the clinical fact that when we have by means of efficient mechanical support, prevented "pronation of the foot," we have relieved the pains in the calf, the knee, and the hip.

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of July 15, 1897.]

A NEW MODIFICATION OF THE HIP SPLINT.[1]

BY JOHN DANE, M.D., BOSTON.

The groundwork for the splint shown in the accompanying picture is what has long been known as the "Thomas knee splint." To this has been added a Burrell screw extension, by which it can be somewhat lengthened as occasion may demand. At the bottom there is a windlass and cog-wheel, whereby traction can be made upon the ends of a plaster extension applied to the leg. At the top it is fitted with a pelvic band similar to that now used upon the Taylor hip splints; but so adjusted by means of a hinge joint, that it can be carried sideways when the splint is being put on, and then locked into position by a simple key. The rather broad leathers are sewed to the outside upright, and go thence around the leg and the inside upright as well, lacing up in the front. The upper one is worn as high as possible, the top of the lower should come just below the patella. The perineal strap (when one is necessary) is made of linked window chain, padded with felting and covered with Canton flannel. This is riveted to the splint behind, and fastened in front by being slipped over a hook. When the proper length has been found, all superfluous links of the chain are cut off.

The advantages claimed for the new splint are:

(1) That while it is as easy to adjust upon a sensitive hip as the common form with two detachable perineal bands, it is more firm when in place.

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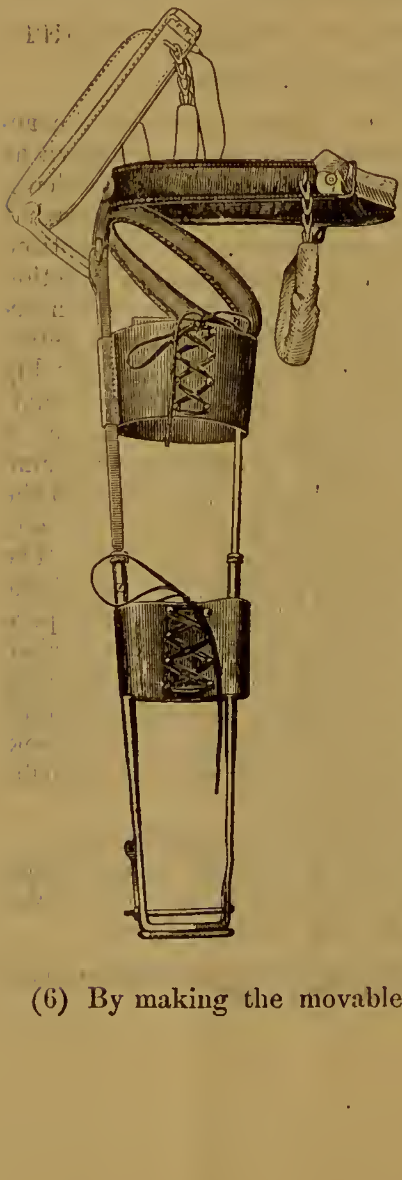
[1] Shown before the American Orthopedic Association at its Annual Meeting held in Washington, D.C., May 4, 1897.

(2) That it cannot be put on wrongly nor worn too high up, as one so frequently finds the splints which depend for their position upon the length of two adjustable perineal bands.



(3) By replacing the counter-pressure of the yielding perineal straps upon the soft tissues of the groin with that of a rigid metal-ring pressing against the tuberosity of the ischium, a firm point of resistance is substituted for a yielding one, and danger from cutting and chafing much reduced.

(4) It is impossible for ignorant parents in out-patient clinics to apply the traction first, and then try and tighten the perineal straps afterwards: the counter-pressure is here the first point established.

(5) It is impossible for a child to loosen the perineal straps and so avoid an uncomfortable amount of traction during the night.

(6) By making the movable perineal strap (where

one is necessary) of metal chain, and cutting it to the desired length, it obtains an unyielding and yet flexible means of support and one that cannot be worn too loose.

(7) By means of the broad leathers, passing around both uprights, the leg is held more firmly in the correct position with less constriction than in the common splint with a single upright, and the tendency to genu-valgum or subluxation of the tibia is greatly lessened.

(8) When used for a walking or convalescent splint, the windlass attachment can be cut off. The round ends of the upright are then bent at right angles with the shaft for the last half inch or so and can be slipped into either end of a small piece of tubing fastened to the heel of the shoe. If the length of the upright has been so fixed that the heel of the foot does not quite come into contact with the heel of the shoe, the weight of the body will, when standing, be supported about equally by each of the uprights of the splint. As a consequence, in walking, the customary unpleasant, sideways lurch due to the necessity of bringing the centre of weight over the single outside upright of the ordinary splint, is in a great measure done away with.